Mechatronics Longa, Vita Brevis: a Concept of Handling Automation by Transactional Analysis and Evolutionary Computation

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***Abstract*— Mechatronics embodies principles that cannot be traced only thousands of years ago in production of human artifacts, but are being present in every form of life and social relationship: we are in era of (re-)revelation and economically efficient applications of *bio*- and *social*-mechatronics. History is full of technological inventions and re-inventions with direct influence to social organisation and stability, as well as individual freedom, productivity (creativity) and tranquility of life. Application of technology implies *transactions*, such as those according to Eric Berne, that may be used in automaton design. Transactions have the features such as: participants and their intentions, content and flow, capacity, sensorics, inference engine, performance, costs and outcomes (profits). The purpose of each transaction is to reach a specific goal, whose outcome has control and executive characteristics. Achievement of more or less rational goals may have potentially distortive effect to equality in transaction and its participants (projected phantasy turned into its opposite). Therefore, evolutionary computation algorithms such as simulated annealing may be used in order to optimize system (automaton) structure and performance (behavior).**

I. Introduction

The first part of the paper presents considerations aimed at development of more general methodology for mechatronic handling system planning. The approach is based on several paradigms taken from engineering and non-engineering domains (CAD/CAE/CAM, concurrent engineering, transactional analysis Berne [1], optimization etc.). The methodology will be proven in experimental work to facilitate complex automaton's behavior. In terms of that, but in a real environment, the second part of the paper deals with path and layout optimization on the basis of travelling salesman problem using simulated annealing.

II. Handling: a part of a process

Handling of single parts occurs in almost every process, either industrial or non-industrial, either technical or biological. Handling covers various aspects of a very important general principle of mobility (that is so important thus even individual real estates pose a threat for mobility of work force).

Typical industrial areas of handling are: transport (in material flow) among machines/workplaces, assembly, packaging and disassembly. The realization of handling process depends mostly on product and its quantities, implying technical systems whose performance in turn yields appropriate costs and profits. Possible market demand for larger production quantities, accompanied with the intent to use sound engineering approaches and technology, indicate a necessity of automated handling, where the goal is to achieve effectiveness through automation, on the levels of: product (and its package) design, process/system planning and process execution (Fig. 1). The issue covers both development of technical system itself as well as development of tools for its realization.

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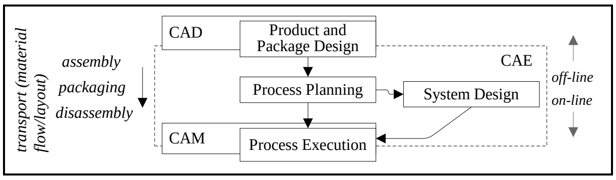

Figure 1. Stages and activities related to handling in product realization

The technical systems aimed at automatic transport, assembly, packaging and disassembly are, despite significant differences (different roles in a production process/product life-cycle), closely related technologies: they have handling as the major activity, so hardware may be mostly the same.

Regarding the levels of automation, it is needed to stress a discrepancy between assembly and packaging, at one side, and disassembly, at the other side. The discrepancy – backwardness of disassembly, exactly shows trend and need for changing of the relationship between industry (engineering work) and natural environment, meaning not only a change of planning content, but also planning approach.

III. Handling and its software

Commercial software still does not seamlessly cover complete planning content, nor is satisfactory automated and structured (a lot of interactive work; design procedures are sometimes redundant, for example in designs of assembly and mechanism).

It can be stated that the use and development of the required planning software support may be viewed from at least five points:

1. general-purpose CAD software (such as: Catia, Pro/ENGINEER, Siemens NX, Google SketchUp, DesignSpark Mechanical);

2. engineering design/planning problem-specific (CAE) software (such was Delmia, now within Catia; Tecnomatix, now with Siemens; CIROS; CapePack and TRUCKFILL; OpenRAVE; ArtiosCAD;);
3. device programming/control (CAM) software (often developed by equipment manufacturers);
4. method-oriented optimization software tools, often stand-alone;
5. business management – enterprise resource planning software (SAP, Oracle).

The engineering use of software (Fig. 2) includes its ability of large-scale visualization, computing and virtualization, which is adequate for engineering mental work of various complexity (from trivial to very creative; the treatment of large assemblies where standard man-computer interfaces become insufficient and virtual reality tools need to occur). However, in last decades the development was pretty slow, from technological euphoria and optimism in the second half of 90's, through market failures (Production Pilot), to today's situation of moderate and muted optimism (Siemens acquisition of EDS/UGS software).

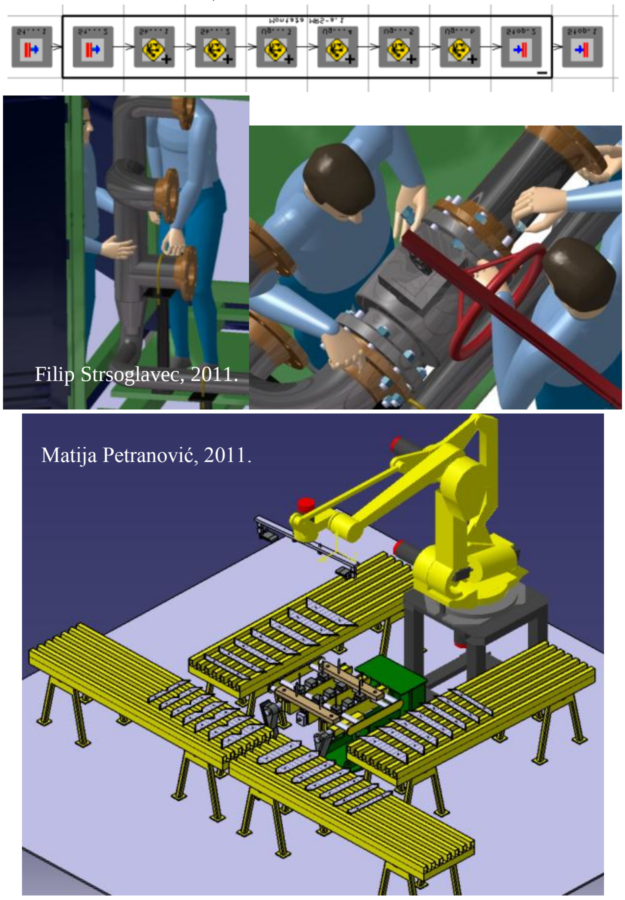

Figure 2. Examples of handling system design, simulation and visualization

Adept's Production Pilot software suite, ten years ago, although as advertised, very advanced even in today's terms, was not successful. One of the main reasons may be too narrow market for such product (system integrator design offices). Why would a manager at assembly plant buy such complex and expansive software if his robots need only minor code modifications in their programs per year? In contrary, the need for off-line programming tool is of essence for planning environments (system integrators). In fact, even in a case of quite simple products, ever growing global atomized labor division (distribution of outsourced work) is a possible threat to an integral nature of the particular product (participants are loosely coupled to achieve the required results without deeper connections and indifferent to establish and share mutual value system, with appropriate negative effects regarding the level of used technology and eventually even product quality).

The trade interest of manufactures helps designers and planners to import equipment in various CAD file formats (Bosch, Adept). Very often, software is developed as an ad-on to a main production program of a particular hardware manufacturer.

IV. Approach

Modern, fair-minded approach considers complete product life cycle, "from needs to absorption, from raw materials to recycling, from cradle to grave" [2], despite present deviations which often happen in profit-only driven product realizations. So mentioned modern trend requires product's integrated considerations, not only from the viewpoint of design, manufacturing and usage [3], but also including what happens to a product after it had been used.

The phenomenon of a product does not exist anymore in light of technical or economic duration only, but in sense of its life cycle, which is motivated by efforts for rational use of natural resources and environment protection. By terminology cradle-grave, it is obviously established analogy between life-less material artifacts and living systems (which in turn shows perhaps further level of our adoration of material and fetishism, neglecting humanity).

A typical part of product life cycle contains the following processes: 1. manufacturing, 2. assembly, 3. packaging, 4. distribution, 5. consumption, 6. collecting, 7. disassembly and disposal.

The most of the products consist of more than one part, so they must be assembled. After assembly, the products are packed and distributed to consumers. Environmental and other reasons require collecting, disassembly and disposal of used products.

Present global market and consumerism establish controversy: we are called to keep the nature and planet, at the same time in which we buy, use and throw away newer and newer products.

It is obvious that solving of such situation will have a strong impact both on society (industrial, trade, legislative) and private (individual) levels, implying increased collaboration, responsibility, obligations and discipline.

It can be assumed, for example, that the collecting system would be much more comprehensive, so the shopping centers will have large areas for receiving used products, including their packages (responsibilities of retailers and customers).

Manufacturing plants would have output and input areas for finished and used products. The manufacturing plant would be responsible for its own product disintegration. It is natural, because the manufacturer has the largest competences (knowledge, facilities) regarding particular product. Despite this, the other closed-loop organizational solutions are also possible (recycling centers – particularly specialized, product specific ones; mixed-product disassembly lines), but it is largely a matter of transportation cost.

Let us imagine a single manufacturing plant – a spot, where all activities of producing of finished goods, as well as disassembling, occur. Each activity may have (for example, because of clean-room, or technological requirements), or may have not (reasons: putting down the equipment investment costs, too low capacity), its own machinery. An order to develop a technical system for a particular task (product) may be treated as an initiation trigger (action stimulus) in specific social and cultural environment and time (initial state), affected by a current level of knowledge and aspirations of potential participants in realization, confronted to external environmental (natural or market) push. There is a system of values with various criteria that can be identified and analyzed in every single planning task which will be in realization (task fulfillment) adequately approved or changed, eventually resulting with further development of (group of) involved participants or their extinction (the latter as an extreme possibility).

Science advances show ever growing similarities between humans and their achievements – technical systems, and it is not hard to imagine near future in which human mental processes will be naked and wirelessly treated.

Traditional industrial conscience requires order, and sometimes bureaucratic acting and environment. That is intrinsic to ancient and always present dialectics of human as a natural and social being, exposed to forces of logos and chaos (rational and instinctive behavior).

Similarly to their own technical systems, and ever growing global profit-only driven specialization in exploitation, humans appear to have very limited chances to realize creative capabilities important for quality and joy of life. Some research showed that excellence in any particular job (mental or physical) requires 10 000 hours to be invested (gradually expressed mass media propaganda of achievements shows a whole range of specialized people: from weird built-own-body individuals, gladiators, state-supported entrepreneurs, physicists in underground tunnels, to modest and more quite ones examples, more acceptable to an old-fashion petit bourgeois reactionary taste).

Any system requires appropriate organization to achieve its own survival, mostly on the basis of criterion in accordance with the principle of minimum energy. Repetition as system’s behavior occurs as answer to inputs (signals) that regularly appear (large production volumes, dedicated equipment). Situation of repetition will always bring specialization and more ordered work expectations and environment, with a tendency to lagging and invariance. Such invariance decreases an ability of adaptation to new, and especially quickly, spreading conditions (signals, criterion in the value system).

At the opposite side, flexibility would always enable easier coping with changes, but in turn, with the lower output (efficiency) – Fig. 3.

Obviously, each system must cope with mentioned dialectics, with its value system (source of volatility).

Figure 3. Specialization, flexibility and labor division

The next rule is that as the (technical) system is more complex its value system should be even more complex to retain and upgrade its current state.

Many historical experiences have shown inability of groups in acting due to in fact trivial reasons (for example, Morrison’s depictions of Guadalcanal sea battles, and more recently, yet many years lasting regional and global crises). Historical knowledge exists, advanced technology, too, but is seems that mankind will repeat the same failures. The reason is a global social production relationship (exploitation frame) that has not been changed in accordance with the change of social forces (people and technology): therefore a regression occurs. Real problems are intentionally overseen [4]. Further, each generation has to learn from scratch.

Growing number of Earth’s inhabitants (the law of supply and demand) requires adequate decrease of labor cost, and Western countries prepare themselves by means, besides, of cost-cutting of social benefits and standard (in health and education). Long time suppressed exploitation principles known from 19th century and Marx’s days come again. Approach to fair distribution of profit is blocked; the decisions are made in smaller and smaller groups. In Western countries deprivation of education and its quality benefits will move back life quality and labor cost very far behind, as adequate preparation for advent of imported work force.

How much can we think beyond our own limitations? Our own limitations (capacity of knowledge reception, processing and upgrade; daily operational push) would too often lead to predefined solutions, and such would be greatly influenced with our position in (social) division of work. Common industrial approaches are based on decent praxis and normative references [5 & 6], though, due to infinite number of products, technical solutions and planning situations, sometimes very hard to generalize to larger extent.

The planning content related to assembly, packaging and disassembly [7] is given by Fig. 4. In a plan generation, as given, the sequence of planning steps is not mandatory in its entirety. Besides, assembly and disassembly are not always inverse.

Software CapePack results with optimal arrangements of different levels of packaging that should be later on transposed to appropriate handling functions (positions and orientations, paths, handling and other functions and operations) performed by human hand or machine. So such arrangements – patterns have important influence on future technical system in sense of layout and number of workstations.

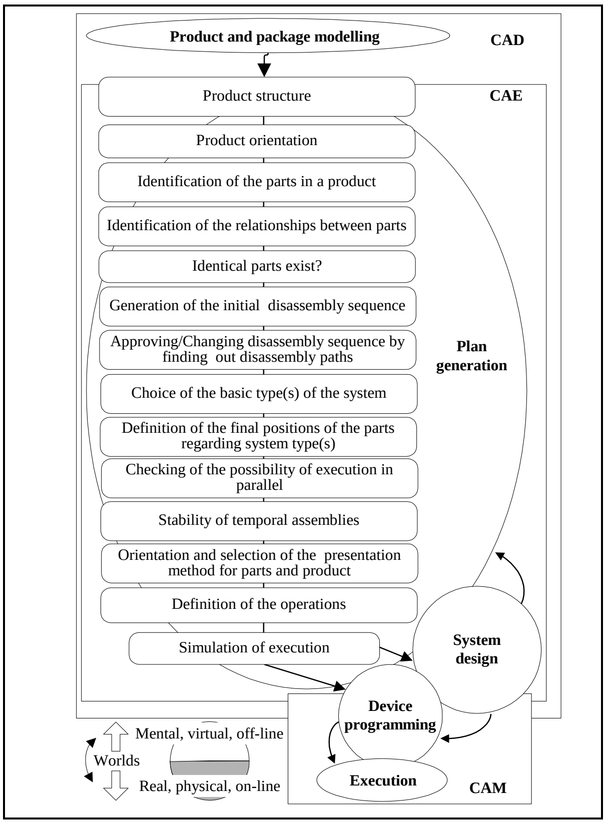

Figure 4. Planning methodology

In a search for the machine, vast space of solutions has to be explored. Reality always tend to evade, despite to number of explorers and their dedication to focus.

V. HANDLING AUTOMATON BASED ON TRANSACTIONAL ANALYSIS

Technical systems are materialisation of humanity. Therefore, the structure and behaviour of technical systems have features that are inherent to humans.

Human survival, playful intellectuality, conscience of its own limitations, loneliness and imperfection have always been mirrored to creation of *deus ex machina*.

Science rapidly unveils similarities between humans and their achievements – technical systems (human mental processes will be naked and wirelessly treated soon).

The technical systems become more and more complicated, on hardware and especially control levels, requiring enlarged effort from their creators.

Here are some features of technical systems inherent to humans:

− minimum efficiency achieved (proved by existence)
− goal-oriented acting and task acomplishment
− output quality and efficiency to be enlarged (natural or market push)
− capacity limit and finiteness
− life cycle usually longer than economic cycle
− structure comprising control (process initialization, corrective and adaptive functions) and executive (operative, outcome/artefact-carrying function) levels
− interactions according to work/labor divison (autonomy and/or group collaboration)
− specialisation/dedication vs. flexibility/versatility
− data processing and symbolic reasoning
− inertia (delays) to changes vs. volatility
− prerequisites for acting (initial conditions, resources, arrangement of environment) and repetition
− different ways (modes) of acting (work content and level of automatic behavior/functioning)
− energy consumption
− desirable and undesirable behaviour depends on current situation which may be difficult to anticipate (Common technical criteria of effectiveness (productivity, costs, time etc.), may be rather considered as dialectical criteria of construction and deconstruction.).

In automaton design, common engineering knowledge and practice will be integrated with those from other, non-engineering, domains. For example, it may be interesting to explore the possibilities of using psychiatric and psychological concepts such as those of:

− S. Freud − three-layer control structure (ego, super-ego, id), and
− E. Berne − transactional analysis − interactions, transactions (stimulus and the response) and structured behaviors and scenarios.

Both concepts are well established and usable, despite everyday brain-mining explorations that would finally reveal human mechatronic shivery we share with other living organisms.

Transactional Analysis was introduced in fifties years of the 20th century by Eric Berne [1]; it is: 1. an easily understandable yet sophisticated psychological theory about people's thinking, feelings and behavior, 2. a system of psychotherapy, education, organizational and socio-cultural analysis and social psychiatry.

People's interactions are made up of transactions. Any one transactions has two parts: the stimulus and the response. Individual transactions are usually part of a larger set. Some of these transactional sets or sequences can be direct, productive and healthy or they can be devious, wasteful and unhealthy. ... Stroking is the recognition that one person gives to another. Strokes are essential to a person's life. ... It has been shown that a very young child needs actual physical strokes in order to remain alive. ... positive strokes like praise or expressions of appreciation, or negative strokes like negative judgements or put downs. Therefore, the exchange of strokes is one of the most important thing that people do in their daily lives. [8]

There is a clear analogy between the latter and any contemporary technical system that requires multi-control dynamics.

Typical sequence in scenario of packaging planning (transitions from idea to realized artifact: sequence of data and material transformations):

1. find arrangement of packaging
2. determine process − handling and other functions (positions and orientations, paths...)
3. define principal technical solutions
4. develop tehnical solutions in detail and integrate
5. definition of control system and programming
6. execution and adaptation.

Types of possible machine regarding its capacity:

– machine with maximum (virtually unlimited) capacity, that collects all presented products in one handling/transport session,

– one-by-one pick and place machine,

– mixed case.

A particular part of the mentioned approach, related to transport path optimization, will be shown in the next section; though, details on experimental apparatus – appropriate product/assembly, software and machinery, and design levels of technical system, will not be covered.

VI. EXAMPLE OF MIXED LINE FEEDING OPTIMIZATION USING SIMULATED ANNEALING

Mixed (-product) line is usual flexible trade-off design of technical solution where product diversity (though very limited) has been met with line efficiency. Layout and path optimization comes as a result of production quantities and dynamics of orders (line feeding). The line design and operation issue will be established as a travelling salesman problem [9–12] on the basis of Simulated Annealing (SA) [13]. The idea of SA comes in 1953 [14] where the algorithm simulated the cooling (annealing) of material in a heat bath. If a solid is heat past melting point and then cooled, the structural properties of the solid depend on the rate of cooling. If the liquid is cooled slowly enough, large crystals will be formed. However, if the liquid is cooled quickly (quenched) the crystals will contain imperfections. The algorithm [14] simulated the material as a system of particles and its cooling process by gradually lowering the temperature of the system until it converges to a steady, frozen state. In 1982 [15] the algorithm was applied to optimization problems to search for feasible solutions and converge to an optimal solution.

The law of thermodynamics states that at temperature, *t*, the probability of an increase in energy of magnitude, δE, is given by:

$$P(\delta E) = exp(-\delta E / kt) \tag{1}$$

where *k* is a constant (Boltzmann's constant), its value depends on material.

The simulation [14] calculates the new energy of the system. If the energy has decreased then the system moves to this state. If the energy has increased then the new state is accepted using the probability returned by the above formula. A certain number of iterations are carried out at each temperature and then the temperature is decreased. This is repeated until the system freezes into a steady state. This equation is directly used in SA, although it is usual to drop the constant *k*. Therefore, the probability of accepting a worse state is given by the equation:

$$P = exp(-c/t) > r \tag{2}$$

where:

c – the change in the evaluation function

t – the current temperature

r – a random number between 0 and 1.

The probability of accepting a worse move is a function of both the temperature of the system and of the change in the cost function. It can be appreciated that as the temperature of the system decreases the probability of accepting a worse move is decreased. This is the same as gradually moving to a frozen state in physical annealing. Also note, that if the temperature is zero, then only better moves will be accepted which effectively makes SA act like hill climbing. The following pseudo-code of algorithm is taken from [13] (similar algorithms may be found in many instances elsewhere):

Function SIMULATED-ANNEALING (Problem, Schedule) **returns** a solution state

Inputs: Problem, a problem
Schedule, a mapping from time to temperature

Local Variables: Current, a node
Next, a node
T, a "temperature" controlling the probability of downward steps

Current = MAKE-NODE(INITIAL-STATE[Problem])

For *t* = 1 **to** ∞ **do**

T = Schedule[*t*]

If *T* = 0 **then return** Current

Next = a randomly selected successor of Current

Λ*E* = VALUE[Next] – VALUE[Current]

if Λ*E* > 0 **then** Current = Next

else Current = Next only with probability exp(–Λ*E/T*).

Several observations about the algorithm can be made. One of the parameters of the algorithm is the cooling schedule, and the algorithm assumes that the annealing process will continue until the temperature reaches zero. Some implementations keep decreasing the temperature until some other condition is met (for example, no change in the best state for a certain period of time). The way this algorithm is presented may hide another aspect of the algorithm that is shown more directly elsewhere. That is, a particular phase of the search normally continues at a certain temperature until some sort of equilibrium is reached. This might be a certain number of iterations or it could be until there has been no change in state for a certain number of iterations. This is all part of the cooling schedule which, in the above algorithm, hides some of these details. The cooling schedule of SA algorithm consists of four components: starting temperature, final temperature, temperature decrement, iterations.

The ***starting temperature*** must be high enough to allow a move to almost any neighborhood state. If is not, the ending solution will be the same (or very close) to the starting solution. Alternatively, a hill climbing algorithm may simply be implemented. In contrary, if the temperature starts at too high value then the search can move to any neighbor and thus transform the search (at least in the early stages) into a random search. Effectively, the search will be random until the temperature is cool enough to start acting as SA algorithm. The problem is finding the correct starting temperature. At present, there is no known method for finding a suitable starting temperature for a whole range of problems. Therefore, other ways need consideration for calculation of a starting temperature: 1. the maximum distance (cost function difference) between one neighbor and another; 2. starting with a very high temperature and rapid cooling until about 60 % of worst solutions are being accepted.

This forms the real starting temperature and it can now be cooled more slowly. A similar idea is to rapidly heat the system until a certain proportion of worse solutions are accepted and then slow cooling can start. This can be seen to be similar to how physical annealing works in that the material is heated until it is liquid and then cooling begins (i.e. once the material is a liquid it is pointless carrying on heating it).

Regrading ***final temperature*** it is usual to let the temperature decrease until it reaches zero. However, this can make the algorithm run for a lot longer, especially when a geometric cooling schedule is being used. In practice, it is not necessary to let the temperature reach zero because as it approaches zero the chances of accepting a worse move are almost the same as the temperature being equal to zero. Therefore, the stopping criteria can either be a suitably low temperature or when the system is “frozen” at the current temperature (i.e. no better or worse moves are being accepted).

Temperature decrement Once starting and stopping temperature are known, it is needed to get from one to the other − to decrement current temperature until eventually arrive at the stopping criterion.

The way of temperature decrement is critical to the success of the algorithm. Theory states that enough iterations should be allowed at each temperature so that the system stabilizes at that temperature. Unfortunately, theory also states that the number of iterations at each temperature to achieve this might be exponential to the problem size. As this is impractical, a compromise is needed: a large number of iterations at a few temperatures, or, a small number of iterations at many temperatures, or, a balance between the two. One way to decrement the temperature is a simple linear method. An alternative is a geometric decrement where:

$$t = t\,\alpha, \quad \alpha < 1. \tag{3}$$

Experience has shown that α should be between 0.8 and 0.99, with better results being found in the higher end of the range. The higher the value of α, the longer it will take to decrement the temperature to the stopping criterion.

The final decision to make is to determine a number of ***iterations*** at each temperature. A constant number of iterations at each temperature is an obvious scheme. Another method is to do only one iteration at each temperature, but to decrease the temperature very slowly. The formula is (β is a suitably small value):

$$t = t/(1 + \beta t). \tag{4}$$

This formula has been entered on a spreadsheet (available from the web site). An alternative is to dynamically change the number of iterations as the algorithm progresses. At lower temperatures it is important that a large number of iterations are done so that the local optimum can be fully explored. At higher temperatures, the number of iterations can be less.

Fig. 5 presents a real layout with several machines of the cable producing company. Material flow is established between a warehouse and every single machine. Transport vehicle transports material one by one from warehouse to appropriate machine and goes back, visiting the same machine locations several times. Transport frequency (*f*), depends on production quantities (customer orders) so it changes dynamically in time.

Length of transport paths depends on distances between locations of warehouse and machines. If the lengths/distances are multiplied by frequencies, total path of the transport vehicle can be stated as change (*shifting*) of *x* and *y* coordinates of locations.

From the viewpoint of transport vehicle, it means that a particular location is always situated in different coordinates. Given that this is a real problem in the production, in which transport vehicle passes many kilometers, the question arises about route optimization in order to reduce fuel consumption and shorten the time of the tour.

Described problem is analogue to that of travelling salesman which visits various towns on different locations (coordinates), so path optimization of transport vehicle visitation of machines is possible.

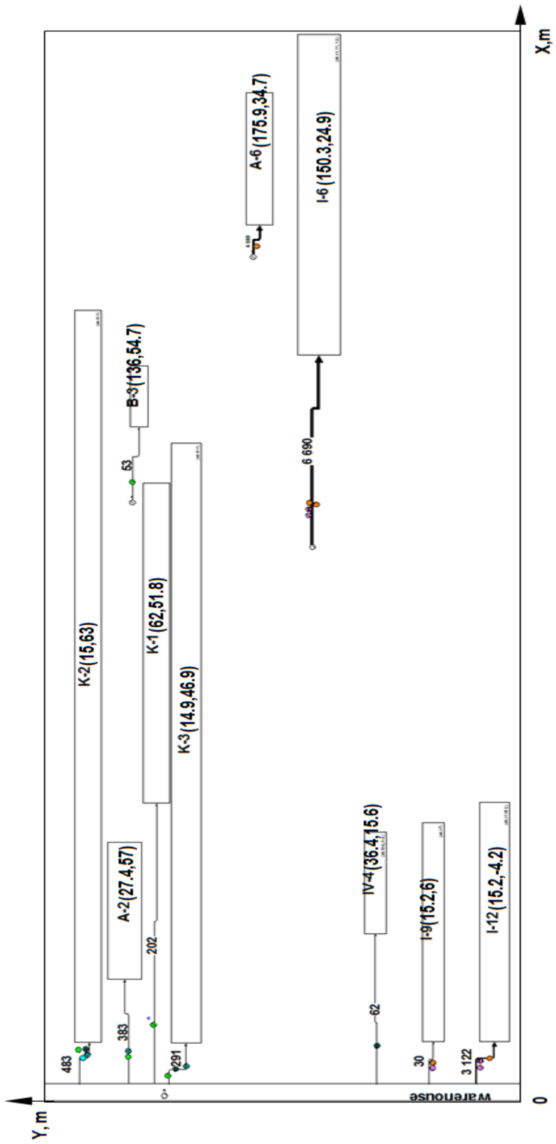

Figure 5. Layout of machines with coordinates

The principle of calculation of location shifting, i.e. values of fictitious (shifted) coordinates (x_2,y_2) in dependency of frequency *f*, is given by (5)–(8), Fig. 6 and Table I.

$$c_1 = \sqrt{x_1^{\,2} + y_1^{\,2}} \tag{5}$$

$$c_2 = c_1 \cdot f \tag{6}$$

$$y_2 = y_1 \cdot \frac{c_2}{c_1} \tag{7}$$

$$x_2 = \sqrt{c_2^{\,2} - y_2^{\,2}} \tag{8}$$

In accordance with previous considerations, two simulations have been performed: 1. transport vehicle visits all locations only once (f = 1); 2. real situation of orders when a frequency of location visitation $f > 1$, what results with fictitious layout different from that in Fig. 5. Both simulations calculate length of total path (route, track) that transport vehicle should travel, for two cases:

1. unoptimized paths (tables II. and IV.), where transport vehicle visits locations randomly,
2. optimized paths (tables III. and V.), determined by SA algorithm.

The figures 7.–10. show unoptimized and optimized routes. *Layout track* implies real path on which transport vehicle moves, while *unoptimized/optimized* track relates to an ideal path. Together with figures 7.–10., accompanied tables II.–V. with the results are given. According to the results, the optimization on the basis of SA algorithm yields:

1. for f = 1, in tables II. and III., shortening of the path for 32 %;
2. for $f > 1$, in tables IV. and V., shortening of the path for 51 %.

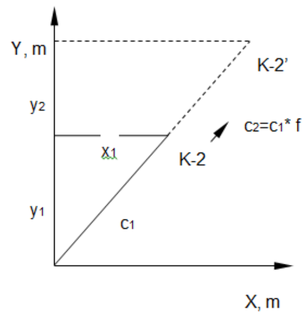

Figure 6. Principle of location shifting based on frequency f

TABLE I.
Original and shifted coordinates of layout locations

Layout location	Original coordinates		Distance c_1	f	Distance $c_2=c_1*f$	Shifted coordinates	
	x_1	y_1				x_2	y_2
–	m			–	m		
K-2	15.0	63.0	64.76	57	3691.38	855.00	3591.00
A-2	27.4	57.0	63.24	383	24222.32	10494.20	21831.00
B-3	136.0	54.7	146.59	53	7769.17	7208.00	2899.10
K-1	62.0	51.8	80.79	41	3312.44	2542.00	2123.80
K-3	14.9	46.9	49.21	291	14320.10	4335.90	13647.90
A-6	175.9	34.7	179.29	4869	872962.95	856457.10	168954.30
I-6	150.3	24.9	152.35	1904	290071.76	286171.20	47409.60
IV-4	36.4	15.6	39.60	62	2455.33	2256.80	967.20
I-9	15.2	6.0	16.34	492	8039.95	7478.40	2952.00
I-12	15.2	–4.2	15.77	3122	49232.66	47454.40	–13112.40

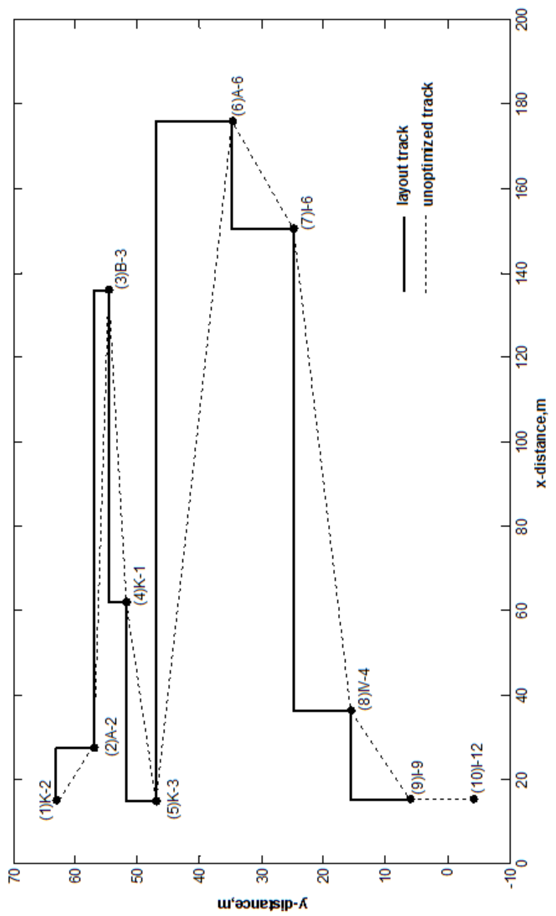

Figure 7. Unshifted and unoptimized routes

TABLE II.
Unshifted and unoptimized distances between layout locations

Route	Layout location	Coordinates		Unoptimized distance between locations
		x_1	y_1	
–	–	m		
(1)	**K-2**	15.0	63.0	
				13.77
(2)	**A-2**	27.4	57.0	
				108.62
(3)	**B-3**	136.0	54.7	
				74.05
(4)	**K-1**	62.0	51.8	
				47.35
(5)	**K-3**	14.9	46.9	
				161.46
(6)	**A-6**	175.9	34.7	
				27.41
(7)	**I-6**	150.3	24.9	
				114.27
(8)	**IV-4**	36.4	15.6	
				23.27
(9)	**I-9**	15.2	6.0	
				10.20
(10)	**I-12**	15.2	–4.2	
Σ				**580.43**

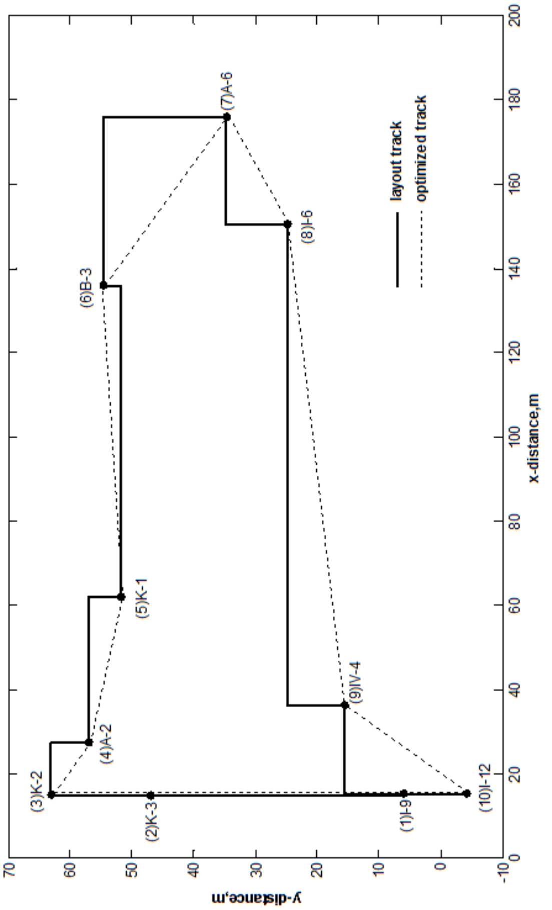

Figure 8. Unshifted and optimized routes

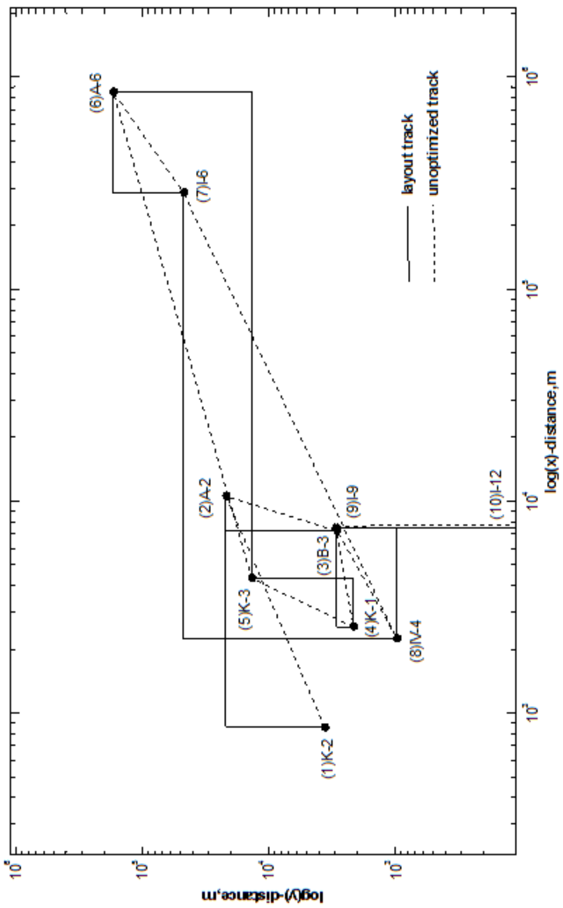

Figure 9. Shifted and unoptimized routes

TABLE III.
Unshifted and optimized distances between layout locations

Route	Layout location	Coordinates x_1	Coordinates y_1	Optimized distance between locations
–	–	m		
(1)	**I-9**	15.2	6	
				40.90
(2)	**K-3**	14.9	46.9	
				16.10
(3)	**K-2**	15'	63	
				13.77
(4)	**A-2**	27.4	57	
				34.98
(5)	**K-1**	62	51.8	
				74.05
(6)	**B-3**	136	54.7	
				44.63
(7)	**A-6**	175.9	34.7	
				27.41
(8)	**I-6**	150.3	24.9	
				114.27
(9)	**IV-4**	36.4	15.6	
				29.00
(10)	**I-12**	15.2	–4.2	
Σ				**395.15**

TABLE IV.
Shifted and unoptimized distances between layout locations

Route	Layout location	Coordinates x_2	Coordinates y_2	Unoptimized distance between locations
–	–	m		
(1)	**K-2**	855	3591	
				20630
(2)	**A-2**	10494	21831	
				19214
(3)	**B-3**	7208	2899	
				4729
(4)	**K-1**	2542	2123	
				11662
(5)	**K-3**	4335	13647	
				866158
(6)	**A-6**	856457	168954	
				583094
(7)	**I-6**	286171	47409	
				287687
(8)	**IV-4**	2256	967	
				5586
(9)	**I-9**	7478	2952	
				43083
(10)	**I-12**	47454	–13112	
Σ				**1 841 848**

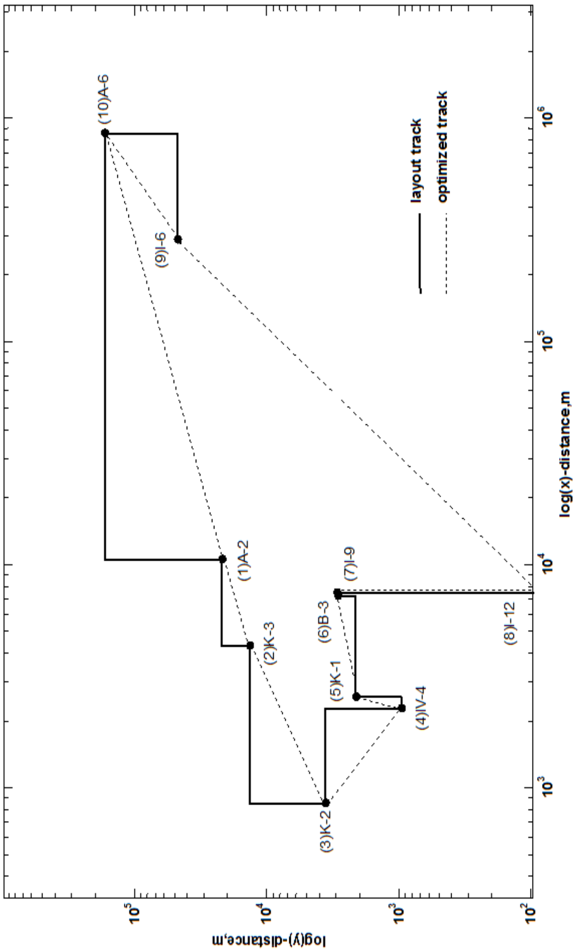

Figure 10. Shifted and optimized routes

TABLE V.
Shifted and optimized distances between layout locations

Route	Layout location	Coordinates x_2	Coordinates y_2	Optimized distance between locations
–	–	m		
(1)	**A-2**	10494	21831	
				10241
(2)	**K-3**	4335	13647	
				10642
(3)	**K-2**	855	3591	
				2974
(4)	**IV-4**	2256	967	
				1191
(5)	**K-1**	2542	2123	
				4729
(6)	**B-3**	7208	2899	
				275
(7)	**I-9**	7478	2952	
				43083
(8)	**I-12**	47454	13112	
				246269
(9)	**I-6**	286171	47409	
				583094
(10)	**A-6**	856457	168954	
Σ				**902 502**

VII. Conclusions

In the dawn of a new totalitarianism, human common sense (reasoning) is oversheded by tehnology if the latter is economically justified. The next generation of closed-loop mechatronic production-consumption-recycling profit-based systems brings further requirements for higher levels of automation, modularity and integration, and the same for their planning. In terms of that arises the importance of development and use of adequate (sometimes even unconventional) planning approaches and software tools that will enable straightforward accomplishment of engineering task in planning of mechatronic systems in the fields of automatic assembly, packaging and disassembly. In further work of special interest will be considering of integration of general CAD software, CapePack, own developed software and laboratory automatic equipment (mobile robots), enabling different production scenarios and mechanical behaviors, avoiding forced behaviour (indiffernece and regression).

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